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DEVICE FOR MEASURING THE VISCOSITY OF FLOWING MEDIA, VISCOSITY SENSOR AND METHOD FOR MANUFACTURING THE ELECTRODES OF A TACHOMETER FOR SAID VISCOSITY SENSOR

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Field of the Invention

The present invention relates to devices for measuring the viscosity of flowing media, wherein said devices include a viscosity sensor of the rotating type. This invention is used for measuring with increased accuracy the viscosity of insignificant volumes of Newtonian and viscoplastic media in which the temperature and pressure vary in a wide range.

Description of the Prior Art

Known in the art is a system for measuring the viscosity of flowing media, comprising a digital converter, a pulse discriminator, a logic device, an electronic switch, a forming device and a logic switching circuit, wherein the input of said converter is connected to the output of the logic frequency comparison device through said pulse discriminator and the output of said logic frequency comparison device is connected through said electronic switch to the rotor of an electric motor of the viscosity sensor inner receiving cylinder, said cylinder having an incremental shaft rotational speed sensor fixed on its shaft, and said sensor is connected through said forming device and an incremental correction device to one input of said logic frequency comparison device wherein the second input is connected to the output of said logic switching circuit. (SU,A, 1276957, IPC G01N 11/14, 1986.)

The known systems for measuring the viscosity of flowing media under high pressure and temperatures that use a viscosity sensor of rotating type are, like that described above, rather complex and, consequently, involve high costs; also they have a limited measurement range and a measuring chamber of great volume as well as do not ensure high measurement accuracy to meet users' needs.

The object of the present invention "Device for measuring the viscosity of flowing media" is to provide a portable and inexpensive device for measuring the viscosity of flowing media, in particular, liquids, by the viscosity sensor rotor speed measured with high accuracy and the rotor torque set with high accuracy. Technically, this invention allows to raise the measurement accuracy to .1 - .5 % in the viscosity range from .01 sP to 30 P for liquids which may be under pressures of 500 MPa or

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more, at temperatures from 0 °C to 160 °C or more, and comprises the rotating sensor measuring chamber the working volume whereof does not exceed 1.5 mL.

The above-said technical result is attained by a known device for measuring the viscosity of flowing media, which includes a viscosity sensor realized from an asynchronous motor and having a measuring chamber, the output of said viscosity sensor being connected to the input of an information-signal generation unit and said measuring chamber being connected through the inlet port to a high-pressure pump, and a tachometer having its rotor rigidly connected to the rotor of said asynchronous motor, both being arranged in said measuring chamber. Said information-signal generation unit is in the form of an AC bridge circuit comprising shoulders which are identical and are each made of a resistor and of a capacitor of variable capacity connected in series. The capacitors of variable capacity are formed by the electrodes of the tachometer stator and by at least one pole of the rotor thereof. This pole is connected to one of the poles of the supply bridge of the generator through a capacitor with fixed capacity that is defined by the surface of the rotor of the asynchronous motor and by the wall of the body of the viscosity sensor. The other pole of the generator is galvanically connected to the common point of the resistors of the different shoulders of the AC bridge circuit, the other ends of the resistors being connected to the inputs of a phase-sensitive converter.

Alternative embodiments of the invention are possible, wherein it is advisable that:

- the generator should be connected to the resistors through a potentiometer;

- the generator should be made controllable by output signal frequency and amplitude;

- the information-signal generation unit should be provided with a low-frequency filter and an amplifier connected in series, the input of the low-frequency filter being connected with the output of a phase-sensitive converter;

- the device should include a temperature control system made in the form of a thermostat connected to a temperature control chamber arranged in the body of the viscosity sensor, a digital multimeter having its signal inputs connected to said amplifier of the generation unit, a pressure gauge hydraulically connected to a high-pressure pump, and a sensor of flowing media temperature in the measuring chamber,

the outputs of said digital multimeter being connected to a controllable power supply of the stator of the asynchronous motor, to said high-pressure pump and to said thermostat for enabling to control, respectively, speed of the rotor of said asynchronous motor, pressure and temperature of flowing media in said measuring chamber.

Known in the art is a viscosimeter of rotating type wherein the rotor having a driven magnet fixed thereto is installed on supports within a hermetic tube, and torque is transferred to said driven magnet from the driving magnet installed on the shaft of an electromechanical drive. A sensor with variable magnetic resistance measures rotational speed of said driving magnet, which in steady-state motion is equal to rotational speed of said driven magnet, said driven magnet being displaced to a small angle relative to said driving magnet by action of viscous friction on said rotor. For measuring said angle there is the second sensor with variable magnetic resistance activated by a ferromagnetic element installed on the rotor. The phase difference between signals generated by both sensors is directly proportional to viscosity. (US Pat. No. 4499753, IPC^6 G01N 11/14, 1985.)

One disadvantage of said viscosimeter of rotating type is that it does not allow significant mismatch of the poles of the driving and driven magnets that limits the measurement range, forcing either to change the rotational speed of the electromechanical drive shaft or to fit the driving and driven magnets depending on the viscosity range of a measured liquid.

Moreover, it is necessary to move to a significant distance the sensor with variable magnetic resistance activated by the ferromagnetic element off the driving and driven magnets to avoid magnetic attraction, which results in an increase in the volume of the chamber filled with a measured liquid and, consequently, in an increase in the volume of the liquid.

Known in the art is a viscosity sensor comprising a body with a measuring chamber, an asynchronous motor wherein the stator is located in the body and the rotor is located in said measuring chamber and in installed on supports, said measuring chamber being connected to the inlet port and the outlet port. The stator of the asynchronous motor is located in the body outside the piping and is separated

from the liquid-containing cavity by the body wall. In a known sensor taken as the prototype viscosity value is judged by the power consumed by the stator. (SU,A, 135691, IPC^6 G01N 11/14, 1960.)

A disadvantage of the said sensor is the lack of specific information on the rotational speed of the rotor, which does not allow fine calibration of viscosity sensors. Moreover, the utilized bearings display a higher friction torque which instability effect on the consumed power rate is impossible to separate from the effect of a change in the viscosity of a liquid.

Another disadvantage of the known viscosimeter is also that the direct contact of the body wall with the stator results in measurement errors due to a deformation the stator resulting from a pressure change in the piping.

The object of the present invention is to provide a viscosity sensor allowing measuring with high accuracy the viscosity of insignificant volumes of flowing media in which the temperature and pressure vary in a wide range.

The above-said technical result is attained by a known viscosity sensor realized from a body with a measuring chamber, an asynchronous motor wherein the rotor is installed on supports and arranged in said measuring chamber connected to the inlet and outlet ports, said body being made as three portions - one central and two lateral ones, the temperature control chamber of the above-said temperature control system and the stator of the asynchronous motor are arranged in the central portion of the body, and said supports of the rotor of said motor are arranged in the lateral portions of the body, the rotor of the tachometer being rigidly and galvanically connected to the rotor of the asynchronous motor and being arranged in the central portion of the body, and said supports being made so as to give possibility of electrically isolate the rotor from the body.

Alternative embodiments of the invention are possible, wherein it is advisable that:

- the stator of the tachometer should be made in the form of at least two electrodes galvanically isolated from each other and arranged opposite its rotor made with at least one pole arranged so as to give possibility to form, with said electrodes, capacitors with variable capacity modulated by the pole when the rotor rotates;

- the central portion and the lateral portions of the body should be made of a chemically inactive and non-magnetic material with low conductance;
- the rotor of the asynchronous motor should be made of a chemically inactive and non-magnetic material having low density and high conductance;
- in a case the rotor of the tachometer is made with two ore more poles, the angular dimension of each of them should be made equal to the angular dimension of the gaps between them;
- each electrode should be made as two groups of plates, said plates in each group being galvanically connected therebetween;
- the gaps between the poles of the rotor should be filled with a dielectric material with the possibility of forming a cylinder.

Known in the art is a method of manufacturing electrodes of a tachometer, consisting in making plates mechanically and fixing them on the dielectric surface of the stator of the tachometer, the plates in each group being galvanically connected therebetween.

The making of the stator of a tachometer according to the known method is technologically difficult and does not ensure compliance with the requirements to the error level of the portions geometry, which significantly lowers the accuracy of a sensor on the whole.

The object of the invention “Method for manufacturing the electrodes of a tachometer” intended for a viscosity measuring sensor is to raise the accuracy and manufacturability of the stator of a tachometer as well as lowering the dimensions and weight thereof, which contributes, when operating the sensor, to raising the accuracy of measurements of the viscosity of flowing media, especially in cases of their insignificant volumes.

In order to achieve the above-said object and get the described technical result in a known method of manufacturing the electrodes of a tachometer, consisting in making, on the stator, said electrodes in the form of combs, the prongs of one of them being arranged in the gaps between the prongs of another one, said electrodes are made in the form of foil which is attached to a polymer film and covered, in segments of its surface corresponding to the form of said electrodes, with a chemically protective substance; afterwards the surface of the film with the foil attached thereto is

treated by etching and the products of etching are removed; afterwards the electrodes are insulated by thermally bonding thereto a film of a hermetic dielectric material; afterwards the two-layer film with said electrodes is rolled up to get the tachometer stator of cylindrical form.

Alternative embodiments of the invention are possible, wherein it is advisable that:

- the boundary areas of the film after making the stator of cylindrical form should be connected therebetween;
- the boundary areas of the film should be connected by overlapping or butting them;
- it is advisable to use a polymer compound as the said dielectric material.

Brief Description of the Drawings

Figure 1 is the electrical schematic diagram of the device for measuring the viscosity of flowing media.

Figure 2 is the functional scheme of an embodiment of the digital multimeter intended for processing of the output signal of the device for measuring the viscosity of flowing media.

Figure 3 is a cross-sectional view of the sensor for measuring the viscosity of flowing media.

Figure 4 is Section A-A for Figure 3.

Figure 5 is Section Б-Б for Figure 3.

Description of the Preferred Embodiments

A device for measuring the viscosity of flowing media, in particular, a liquid, comprises a viscosity sensor 1 (Figs. 1, 3, 4, 5) made with a measuring chamber 2 wherein the rotor 3 of an asynchronous motor is arranged, being rigidly and galvanically connected to the rotor 4 of a tachometer.

The output of the sensor 1 is connected to an information-signal generation unit 5, which characterizes the viscosity of an investigated liquid, and the measuring chamber 2 is connected through its inlet port 6 with a high-pressure pump 7 and through its outlet port 8 with a sensor 9 of temperature of an investigated liquid 10 in the measuring chamber 2.

The body of the sensor 1 (Fig. 1) consists of three portions, the central one 11 and the two lateral ones 12 and 13 wherein the inlet port 6 and the outlet port 8 are

arranged. All said portions of the body are made of a chemically inactive and non-magnetic material with low conductance. It enabled to raise the chemical resistance of the measuring chamber 2 to attacks of corrosive media. Supports 14 of the rotor 3 of an asynchronous motor, which is arranged in the central portion 11, are located in the lateral portions 12, 13 of the body. For the purpose of raising accuracy at the expense of reducing instability effect of friction torque the supports 14 are realized from stone supports or from precision radial thrust bearings.

The measuring chamber 2 in the central portion 11 (Figs. 3, 4) includes the stator 21 of a tachometer which rotor 4 is rigidly and galvanically connected to the rotor 3 of an asynchronous motor, forming a single component. The stator of said asynchronous motor is arranged in the central portion 11 of the body with the possibility of enclosing the rotor 3.

An information-signal generation unit is made in the form of an AC bridge circuit comprising shoulders which are identical and are made of capacitors 16, 17 with variable capacity and of resistors 18, 19. The capacitors 16, 17 with variable capacity are formed by the electrodes 20 of the tachometer stator 21 and by at least one pole 22 of the rotor 4 of the tachometer. The said pole is connected to one of the poles of the supply bridge of the generator 24 through a capacitor 23 with fixed capacity which is defined by the surface of the rotor 3 of an asynchronous motor and by the wall of the central portion 11 of the body of the viscosity sensor 1. The other pole of the generator is galvanically connected to the common point of the resistors 18, 19 of the different shoulders of the AC bridge circuit, the other ends of said resistors 18, 19 being connected to the inputs of a phase-sensitive converter 25.

The generator 24 may be made controllable and is connected to the ends of the resistors 18, 19 through a potentiometer 26.

A low-pass filter 27 and an amplifier 28 are connected in series and to the output of the phase-sensitive converter 25. A signal from the amplifier 28 goes to the signal input of a digital multimeter 29 made with three outputs connected to the asynchronous motor, a high-pressure pump 7 and a thermostat 30, giving the possibility of controlling, respectively, the speed of rotation of the rotor 3 of the asynchronous motor, pressure and temperature of a flowing media in the measuring

chamber 2. A pressure gauge 31 and a flowing media temperature sensor 9 in the measuring chamber 2 are used for measuring pressure and temperature.

The viscosity sensor 1 includes a temperature control system made in the form of a thermostat 30 connected to a temperature control chamber 32 with a heat carrier. The temperature control chamber 32 is arranged in the central portion 11 of the body and is intended for maintaining a stable temperature in the measuring chamber 2. The temperature of an investigated liquid is controlled by the thermostat 30 according to signals from the temperature sensor 9 arranged in the measuring chamber 2 for the purpose of ensuring the value set for measuring temperature of an investigated liquid. The thermostat 30 may be, e.g., a circulation thermostat made by Petrotest Instruments GmbH & Co KG, which adjusts the temperature of an investigated liquid to a set value "T". The temperature sensor 9 is used as a feedback device, which monitors the actual temperature "T_r" of an investigated liquid. The thermostat 30 compares said actual temperature to the set temperature value "T", changes the heat carrier temperature in the temperature control chamber 32 to a corresponding temperature "T_{const}" that ensures the set temperature value "T" of an investigated liquid 10.

The stator 21 of a tachometer is made in the form of at least two electrodes 20 galvanically isolated from each other and arranged opposite the rotor 4 of the tachometer made with at least one pole 22. Said rotor 4 of the tachometer is arranged so as to give possibility to form, with said electrodes 20, capacitors 16, 17 with variable capacity modulated by the pole 22 when the rotor 4 of the tachometer rotates.

In a case where the rotor 4 of the tachometer is made with two or more poles 22, the angular dimension of each of them is made equal to the angular dimension of the gaps between them.

In order to raise the modulation frequency as well as to reduce the axial dimensions of the measuring chamber 2, the electrodes 20 (Fig. 4) are made in the form of groups of electrode plates 33, 34 galvanically connected therebetween in each group, the number of poles 22 on the rotor 4 of the tachometer being made equal to the number of plates in a group. The electrodes 20 are connected by their terminals to the inputs 35 that are hermetically arranged in the central portion 11 of the body.

Figure 4 is a cross-sectional view of an embodiment of the central portion 11 of the body of the sensor 1 comprising a bore wherein an insulating bushing 36 is arranged.

The electrode plates 33, 34 are connected to the terminals of the hermetic high-pressure inputs 35, and the said inputs are insulated with a dielectric material, such as a polymer compound.

The electrode plates 33, 34 are made in the form of combs, the prongs of one of them are arranged relative to the prongs of the other combs with a shift along the axis of the rotor with the possibility of forming, in interacting with its poles, information capacities of differential type.

According to the invention, the electrodes are made as follows. The electrodes 20 (Figs. 4, 5) are made in the form of foil that is attached to a polymer film 37. The surface of the electrodes is covered with a chemically protective substance; afterwards the surface of the film 37 with the foil attached thereto is treated by etching; afterwards the electrodes are insulated by thermally bonding thereto a film 38 of hermetic dielectric material. Afterwards the films bonded to each other are rolled up to get the tachometer stator 21 of cylindrical form and are placed into the bushing 36.

The boundary areas of the films after making the stator of cylindrical form are connected therebetween by overlapping or butting them.

Figure 4 is a cross-sectional view of the rotor 4 of the tachometer, which comprises four poles 22. The gaps between the poles 22 are filled with a dielectric compound 39 with the possibility of making a cylindrical form corresponding to the form of the rotor 4 arranged with a clearance inside the stator 21 made as described above.

Such solution enables to raise the accuracy of measurements at the expense of reducing hydraulic loss effect on vortex formation.

Such a system gives a possibility of measuring the viscosity of an investigated liquid at high temperatures and pressures in the measuring chamber of insignificant volume.

Figure 2 is a functional scheme of an embodiment of a digital multimeter 29, which comprises a combined "volt - ampere" meter 40, an input device 41, an AD converter 42, a RAM device 43, a microprocessor 44, an indicator panel 45, a ROM device 46, a keyboard 47, a control bus 48, an address bus 49, a data bus 50 and an interface 51.

The digital multimeter 29 with the built-in microprocessor 44 is a general-purpose multifunctional metering device enabling to detect and monitor parameters of electric signals coming to its signal inputs from a temperature sensor 9 and a pressure gauge 31. Moreover, proceeding from results of measuring and monitoring parameters of said input signals, the digital multimeter 29 may set and change operating modes of the device according to a given program.

The input device 41 is intended to convert input signals into identical electric signals standard in their forms and ranges of variance.

The AD converter 42, jointly with the RAM device 43, in quantizing each instantaneous value of an analog waveform coming to its input from the output of the input device 41, represents it by the nearest standard value and instruments analog electric input signals into digital code.

The microprocessor 44 is intended to: perform autocalibration of supply voltages and measuring means of the device and autosetting of measurement limits for the parameters monitored; control the process of measuring the viscosity of an investigated liquid under a given program; perform statistical manipulation of data on the measured viscosity of a liquid (estimate, under a known algorithm, an average value of a measured parameter, its variance and standard deviation, etc.); control the process of visualization and registration of received data; exchange information flows with peripheral devices; perform diagnostics of the functional units.

The indicator panel 45 is intended for digital presentation of received data on the viscosity of an investigated liquid as well as for visualization of characters and words informing the operator of the procedure of his further actions.

The ROM device 46 is intended to store the resident and modified programs.

The control keyboard 47 is intended for inputting a work program into the ROM device 46 in a symbolic language.

The interface 51 is intended for interfacing the units being included into the digital multimeter 29 as well as the communication links thereof, namely, the control bus 48, the address bus 49 and the data bus 50 that ensures the translation of the measurement results.

The viscosity sensor operates as follows.

In accordance with a program stored in the memory of the digital multimeter 29, in a time interval "t" after switching on the power supply, all the means of the device become ready to routine operations in the continuous mode of measuring the

viscosity of a liquid 10. The adjustable high-pressure pump 7 and the thermostat 30 ensure a set pressure "P" and temperature "T" of the liquid 10 in the measuring chamber 2.

The high-frequency generator 24 powers the bridge circuit 15 with alternating sine-wave voltage of a frequency of app. 10 kHz.

By the time "t" at a set pressure "P" and temperature "T" the rotational frequency "f" of the tachometer rotor 4 in an investigated liquid 10 becomes stable. A stable frequency 'f" means that a calibration torque applied to the rotor 3 from the stator 52 of the asynchronous motor becomes a balanced braking torque acting on the rotor thereof, which represents the sum of the braking torque in the supports and the moment of viscous friction forces generated by an investigated liquid 10 at a given rotational frequency of the rotor 4. The friction torque value in the supports is taken into account proceeding from the results of calibrating the rotary sensor, and in this condition the rotational frequency "f" of the rotor 4 may be regarded as inversely proportional to the viscosity of an investigated liquid 10.

The rotational frequency "f" of the tachometer rotor 4 is varied by the information-signal generation unit (Fig. 1) realized from a measuring AC bridge circuit 15, a phase-sensitive converter 25 and a low-pass filter 27. It is done as follows. Interaction of the poles 22 with the electrodes 20, while the tachometer rotor 4 is rotating, results in harmonic modulation on the same frequency "nf" of the capacities of the capacitors 16 and 17, where "n" is the number of poles 22 of the tachometer rotor 4. The capacitors with variable capacity 16 and 17 are formed, respectively, by the electrodes 20 interacting with the poles 22. Modulation of variable capacities of the capacitors 16 and 17 occurs in antiphase. A signal resulting from modulation of variable capacities of the capacitors 18 and 19 is fed to the input of the phase-sensitive converter 25. From the output of the phase-sensitive converter 25 a detected harmonic electric signal of an "nf" frequency is applied through the low-pass filter 27 to the input of the DC amplifier 28. From the output of the DC amplifier 28 an amplified signal of an "nf" frequency is applied to the input device 41 of the digital multimeter 29. The input device 41 of the multimeter 29 transforms such signals into identical electrical signals of standard form, i.e., signals with amplitude that is constant and does not depend on relative permittivity of a liquid 10. Normalized signals are applied to the input of the AD converter 42 of the multimeter 29. The AD converter 42, jointly with the RAM device 43, in quantizing each

instantaneous value of an analog waveform coming to its input from the output of the input device 41, represents it by the nearest standard value and instruments analog electric input signals into digital code. In the result, electrical signals are applied to the input of the microprocessor 44 of the digital multimeter 29 in the form of recurring codes - groups of equidimensional pulses of high standard frequency.

The duration t_k of each pulse, as measured by counting the number of time marks included therein, is inversely proportional to frequency "f" and directly proportional to the viscosity of an investigated liquid 10.

The viscosity value "η" is calculated by the microprocessor 44 in accordance with the following relation:

$$\eta = \eta_0 J\varphi^2 t_k \quad \ldots \quad (1)$$

where "$J\varphi^2$" is an active in each phase value of current powering the tachometer stator 4, which is set by the microprocessor, and "η_0" is the constant certified for each sensor 1, which is determined in the result of calibration thereof.

The data, thus obtained on the parameter of an investigated liquid 10, may be supplemented with results of statistical manipulation thereof. All such information as a whole or in part may be presented, if necessary, on the indicator panel 45 as well as registered by the RAM device 43 and the ROM device 46.

Errors like zero drift and instability of a scale parameter are minimized by the calibration operation.

Precision calibration, which allows for, in particular, the effect of the geometric parameters of the sensor 1 as well as the effect of friction in the supports 14 of the rotor 3 of an asynchronous motor, is conducted on the basis of the relation (1) by separately measuring a known viscosity of any liquid for which the viscosity coefficient at definite pressure and temperature is known with the required accuracy.

A high accuracy level for the sensor is ensured, principally, by utilizing therein low-noise insulating supports 14 in the form of stones or precision radial thrust bearings in an insulating race for suspending the rotor 3 of an asynchronous motor, which is made integral with the tachometer rotor 4, as well as by reducing measurements of rotational frequency of the tachometer rotor 4 to an extra accurate type of measurements - digital measurement of time intervals.

Industrial Applicability

The invention complies with the "industrial applicability" criterion, since it can be worked with the use of existing production facilities and known technologies.